APPLICATION FOR
UNITED STATES PATENT

in the names of

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of

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for

SUPPORT APPARATUS AND METHOD FOR USE WITH A CAMERA AND STROBE LIGHTS

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BACKGROUND

[0001]   The present invention relates to a camera support device for taking photos. Many digital image processing operations require specialized equipment to gather data before the digital image processing technique can be performed. Polynomial texture mapping is one such digital image processing technique. The technique is described in U.S. Pat. No. 6,515,674 issued Feb. 4, 2003 assigned to the assignee of the present invention and entitled "Apparatus for and of Rendering 3D Objects with Parametric Texture Maps," by Gelb, Wolters, and Malzbender, as well as in "Polynomial Texture Maps," by T. Malzbender, D. Gelb, and H. Wolters, In *Proceedings of ACM SIGGRAPH 2001*, pp. 519–528, Aug. 12–17, 2001.

[0002]   Once photos are taken with the equipment, polynomial texture mapping processing allows the user to interactively alter the apparent position of the light source in an image as well as its apparent image texture while observing the image on a computer display. For example, a photograph of a valuable archeological artifact can be processed in such a way as the light source can appear directly over the artifact, yielding a low-contrast image. Similarly, the apparent position of the light source can be moved to a very low angle with respect to the artifact, producing a higher contrast image. Beyond this, the apparent surface texture and color of the artifact can be changed from dry and dull white to an oily shiny black finish with the tiny details highlighted by specular reflections.

[0003]   Powerful visual results from polynomial texture mapping make it a useful technique for the close examination of precious artifacts or forensic evidentiary material that is subject to rigorous handling restrictions. Unfortunately, this technique is currently restricted to the laboratory, because a large hemispherical dome used to support the camera and various strobe lights is bulky and difficult to transport. Consequently, this makes *in situ* examination of artifacts or evidentiary material problematic and limits the use of this image processing technique.

[0004]   Other powerful image processing techniques also require specialized equipment to obtain photographs. These other image processing techniques requiring extensive equipment and lighting may also be limited to a laboratory setting like polynomial texture mapping. Accordingly, there is a need to develop more portable and cost-effective equipment for gathering data for use with polynomial texture mapping and other image processing operations.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005]   FIG. 1A is a perspective view of the support apparatus according to one embodiment of the present invention;

[0006]   FIG. 1B is a perspective view of the support apparatus with the light-shielding screens attached, according to one embodiment of the present invention;

[0007]   FIG. 2 is a side view of the support apparatus according to one embodiment of the present invention;

[0008]   FIG. 3 is a side view of a self-propelled mobile strobe light assembly according to one embodiment of the present invention;

[0009]   FIG. 4 depicts a sequence of strobe light firings according to one embodiment of the present invention;

[0010]   FIG. 5 is a flowchart diagram of the operations pertaining to acquiring polynomial texture mapping data using manually positioned strobe lights according to one embodiment of the present invention; and

[0011]   FIG. 6 is a flowchart diagram of the operations pertaining to acquiring polynomial texture mapping data using automatically positioned strobe lights according to one embodiment of the present invention.

[0012]   Like reference numbers and designations in the various drawings indicate like elements.

SUMMARY OF THE INVENTION

[0013]   One aspect of the present invention features a support apparatus for a camera and strobe lights. The support apparatus includes a mounting plate for holding the camera above and at a fixed distance from the photograph area, a set of legs attached to one or more portions of the apparatus providing support and positions for mounting and a set of strobe lights affixed to the legs at known positions relative to the focal plane of the camera and directed towards the photograph area to facilitate acquisition of multiple photographic images capable of use in one or more image processing operations.

[0014]   Another aspect of the present invention also features a support apparatus for a camera and strobe lights. This support apparatus includes a mounting plate for holding the camera above and at a fixed distance from the photograph area, a set of legs attached to one or more portions of the apparatus providing support and positions for mounting and a mobile strobe light slidably coupled to each leg, capable of self-propelled linear motion along the axis of the leg and providing indication of its position along the leg to facilitate acquisition of multiple photographic images capable of use in one or more image processing operations.

DETAILED DESCRIPTION

[0015]   Embodiments of the present invention concern the use of specialized data gathering equipment for various image-processing operations. While the description contained herein describes polynomial texture mapping as one image processing operation, many other image processing operations would also benefit from embodiments of the present invention. For example, alternate embodiments could be used to gather data for an image processing technique called "shape from shading" that recreates the shape of an object according to the various shades and/or shadows caused by the interplay of light upon the object. Accordingly, the mention of polynomial texture mapping is described as a convenient way of describing one embodiment of the present invention and should not serve to limit any aspect of the invention to polynomial texture mapping or any particular feature included or excluded specifically for this one purpose or application.

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[0016] Polynomial texture mapping is one exemplary image processing operation that allows an image of an object to be interactively manipulated in a way as to reveal extremely fine or faint details. The details revealed are far beyond those revealed by simple contrast enhancement of an ordinary photograph. This ability to enhance and reveal extremely faint detail makes polynomial texture mapping a valuable tool for *in situ* forensic evidentiary examination, archeological artifact examination, and other detailed study where there is insufficient detail exhibited by ordinary photographs.

[0017] The data for polynomial texture mapping includes multiple images of a specimen object. The images are taken with a digital camera in a fixed position above the object. Each image is lit by a light source at a different position. Typically, a number of different angles around the object (azimuth) and different elevations with respect to the horizontal plane of the object are used to position the light source for each image. These angles around the object are also referred to as azimuth positions.

[0018] Aspects of the present invention are advantageous in at least one or more of the following ways.

[0019] Embodiments of the present invention allow the image data for polynomial texture mapping to be easily collected in the field using a portable support apparatus for the camera and strobe lights. The support apparatus comprises a special camera mounting plate that allows the camera to take photographs through an aperture in the mounting plate. This allows the camera to be positioned at a fixed distance above the area being photographed. The legs, which can be attached to the mounting plate, further providing support for the strobe lights.

[0020] Strobe lights mounted on different legs allow different azimuthal images to be acquired as rapidly as the camera can be cycled and the strobe lights flashed. The strobe lights are slidable along the length of the legs and fixable at known distances from the focal plane of the camera. Strobe lights mounted at or moved to different points of fixation along the length of the leg allow different elevation

images to be acquired. Additionally, the strobe lights are rotatable around the axis of the leg facilitating compaction and transportation of the support apparatus.

[0021] Further embodiments of the present invention allow the strobe lights to move automatically along the length of the leg. This allows the rapid and accurate collection of large numbers of images for polynomial texture mapping. This is highly advantageous to the gathering of forensic evidence where time at the scene of the evidence may be limited and accuracy in obtaining evidentiary material is of the utmost importance.

[0022] While not illustrated specifically, additional legs can be added to increase the number of azimuthal positions for the lights. These additional legs can provide added support for the overall structure or apparatus or may extend downward without contacting the ground or providing further support. For example, a tripod is illustrated using these support legs. However, a lesser or greater number of legs can be used to support the apparatus. Moreover, a monopod (*i.e.,* one support leg) can be combined with several non-supporting legs extending downward to provide additional azimuthal mounting points for lighting and other accessories. This monopod would be highly portable and functional, yet may be less stable in operation

[0023] Turning first to **FIG. 1A**, a perspective view of the camera and strobe support apparatus is illustrated according to one embodiment of the present invention. A camera **102** is mounted facing down towards a photograph area **110** and is supported by a mounting plate **104**. Mounting plate **104** has an aperture **105** that allows the camera **102** to see a photograph area **110**. A set of legs **106**, connected to mounting plate **104**, supports mounting plate **104** and camera **102** in a stable manner. Connected to legs **106** is a set of strobe lights **108** that can be directed towards a specimen object **112** within photograph area **110**. The portability of the support apparatus allows camera **102** to be positioned above the specimen object **112**. **FIG. 1B** shows light-shielding screens **114** attached between legs **106**.

[0024] Camera **102** is generally a digital camera. The digital camera is advantageous to polynomial texture mapping because polynomial texture mapping

readily adapts to the camera's digital image data. It is also very convenient to use digital photography. For example, having the image in digital form eliminates the time-consuming steps of film development and digital scanning of multiple film images.

[0025]　Mounting plate 104 holds the camera 102 with its lens facing down and substantially normal to and at a fixed distance from the area being photographed. Aperture 105 in mounting plate 104 allows the camera to see photograph area 110 directly beneath camera 102. In alternate embodiments, camera 102 is mounted on the bottom surface of mounting plate 104 or mounting plate 104 is comprised of an optically clear material with camera 102 mounted on its upper surface. Legs 106 securely support the mounting plate.

[0026]　In one embodiment of the present invention, legs 106 are a set of three legs attached to mounting plate 104 that form a tripod. In yet another embodiment, legs 106 have a telescoping feature to aid in the compaction and transportation of the support apparatus.

[0027]　Attached to legs 106 are strobe lights 108. The various mounting points of strobe lights 108 allow acquisition of a number of differently lit images of specimen object 112. For each image, a single strobe light from strobe lights 108 is flashed or "fired" while the shutter of camera 102 is open. Additionally, each image is lit by a differently positioned strobe light in strobe lights 108. In other words, for polynomial texture mapping, no two images in the image set are lit from the same position.

[0028]　The firing of the strobe lights 108 can be accomplished with a sequencing device. Using the sequencing device, the shutter of camera 102 is opened, a single strobe light from strobe lights 108 is fired once, and then the shutter of camera 102 is closed. The captured image is stored and a different strobe light from strobe lights 108 is selected and the process is repeated until all strobe lights 108 have been fired. Moving the strobes to different known positions along legs 106 and repeating the above sequence allows the acquisition of additional images.

[0029]   Frequently, in forensic evidentiary photography, archeological photography, or in other photographic scenes, it is desirable to photograph specimen object **112** *in situ* without disturbing either the object or its environment. The portability of the support apparatus allows it to be positioned so that specimen object **112** resides within the center of photograph area **110**. In police work, *in situ* photography and evidence gathering is particularly important. For example, frequent moving or handling of evidentiary material may result in a complex chain of custody. This chain of custody may impact the value of the evidence due to the increased possibility of tampering or contamination. Using polynomial texture mapping photography to capture evidence *in situ* results in a shorter chain of custody and increased evidentiary value of specimen **112** and other photographed items.

[0030]   As previously described, polynomial texture mapping relies on a set of data images, each lit from a different single point. It is therefore desirable to exclude ambient light from the area being photographed **110**. Light-shielding screens **114**, shown in **FIG. 1B**, serve to block out ambient light and ensure that each image is lit by light from only the strobe light that is fired. In one embodiment of the present invention, light-shielding screens **114** are attached between adjacent legs **106**. The screens can be composed of either rigid or flexible material. In another embodiment of the present invention, screens **114** roll out from legs **106** and attach to adjacent legs **106**. Alternate embodiments that construct the screens **114** from a material that blocks infrared as well as ultraviolet light allow polynomial texture mapping to be performed with light frequencies outside the visible spectrum.

[0031]   Turning now to **FIG. 2**, a side view of the support apparatus according to one embodiment of the present invention. A camera **202** is attached to a camera bracket **210**, which in turn is attached to a mounting plate **212**. Attached to camera **202** is its lens **204**, which forms a focused image at the focal plane **206** of the camera **202**. Mounting plate **212** has an aperture **213** allowing the camera's field of view **208** to be unobstructed by mounting plate **212**. Attached to the mounting plate **212** is a set of legs **214**. Attached to legs **214** is a set of strobe light assemblies as exemplified by strobe light assembly **215**. In one embodiment,

strobe light assembly **215** is comprised of a swivel mounting-ring **216** connected to its associated leg **214**. A ball joint **218** connects swivel mounting-ring **216** to a strobe light body **220**. Attached to strobe light body **220** is a strobe lamp reflector and lens **222**.

[0032]   As previously described, camera **202** is typically a digital camera that mounts, with lens **204** facing down along the length of camera mounting-bracket **210**. With conventional camera tripods, this type of mounting is problematic due to the obstruction of the camera's field of view by either the mounting plate or the legs. Embodiments of the present invention employ a mounting plate with an aperture **213** allowing the camera's field of view **208** to be unobstructed by either mounting plate **212** or legs **214**.

[0033]   Camera lens **204** can be either a fixed focal length lens or it can be a variable focal length zoom lens. The zoom lens allows optimal framing of the object being photographed, yielding more detail. In either of these lens embodiments, the shorter the lens focal length, the wider the field of view **208**.

[0034]   Camera lens **204** typically has a built-in automatic diaphragm to control the depth of focus and the amount of light reaching the image sensor (not shown) mounted inside the camera at the focal plane **206**. This type of lens is termed an "automatic lens." An automatic lens allows focusing with its diaphragm set at its widest opening. This yields a bright image with a narrow depth of field, allowing the proper focus to be readily determined.

[0035]   In one embodiment of the present invention, three of legs **214** form a tripod. The tripod configuration of the legs provides a stable structure for the support apparatus. Legs **214** are provided with detents at known positions so that various strobe light assemblies such as strobe light assembly **215** can be placed at different positions along the leg to increase the number of images for the polynomial texture mapping data set. The detent positions can be linearly spaced or non-linearly spaced along the length of the leg. For example, one non-linear spacing of the detents can make moving to the next detent result in a constant elevation angle displacement with respect to the horizontal plane. Fixed detent

positions are advantageous because they reduce the error in the placement of strobe assembly **215**.

[0036]   In another embodiment, the strobe assembly **215** can be affixable along the axis of a bar mounted at least at one point to at least one leg. For example, mounting the strobe assembly **215** at different points along a bar mounted horizontally between two legs would result in a different azimuth angle for the strobe light as it was affixed at each mounting point.

[0037]   Swivel mounting-ring **216** attaches strobe assembly **215** to each of legs **214** in a slidable manner. In addition to permitting strobe assembly **215** to be moved up and down the leg, swivel ring **216** allows strobe assembly **215** to be rotated around the axis of the leg, allowing legs **214** to be compactly folded together for transportation of the support apparatus.

[0038]   Ball joint **218** allows vertical and horizontal movement of strobe body **220** so that strobe lamp reflector and lens **222** can be directed towards the subject, regardless of the position of strobe assembly **215** along its associated leg **214**. For example, if strobe assembly **215** is positioned near the bottom of its associated leg **214**, then strobe body **220** should be pointed at an angle close to the horizontal plane. If strobe assembly **215** is positioned near the top of its associated leg **214**, then strobe body **220** should be rotated closer to vertical.

[0039]   Strobe body **220** serves to hold a strobe lamp and serves as a mounting point for strobe lamp reflector and lens assembly **222**. Strobe lamp and reflector and lens assembly **222** provides an even field of illumination over the photograph area.

[0040]   **FIG. 3** shows a side view of a mobile strobe light slidably coupled to a leg **306** in accordance with one embodiment of the present invention. A self-propelled mobile assembly **302** is capable of linear motion along the length of leg **306**. The position of mobile assembly **302** is sensed by position sensor **304**. Coupling **310** allows strobe light **308** to rotate in the vertical plane. The rotational motion of strobe light **308** is motorized and can be controlled independently of the motion of self-propelled mobile assembly **302**.

[0041]   Self-propelled mobile assembly **302** allows strobe light **308** to be automatically positioned along the length of leg **306**. Self-positioning of the strobe light is advantageous in that it saves time when collecting a large number of images and it assures accuracy in positioning strobe light **308**. Speed and accuracy are very important factors in the collection of forensic evidence.

[0042]   An internal motor propels mobile assembly **302**. A typical motor for this type of application is a stepper motor. Instead of spinning continuously, the stepper motor rotates in small increments or steps and is often used in printers and plotters where there is much start-stop motion and accurate positioning is required. Power to the motor can be supplied via insulated rails **303** to a brush assembly inside mobile assembly **302**. Commands to the motor can be supplied via a similar third rail **305**. To facilitate compaction of the support apparatus, mobile assembly **302** is removable from leg **306**.

[0043]   As previously described, it is desirable that the position of the strobe light be known for each image in the polynomial texture mapping data set. Position sensor **304** determines the position of mobile assembly **302** along leg **306**. Position along the leg can be encoded in a variety of ways including an optical Gray code, optical bar code, or mechanical detents sensed with micro switches. Optically sensed Gray codes are often used to convey positional information in mechanical devices. A Gray code is attractive for use in position sensing because there is no chance for a single bit error to introduce ambiguity as the code changes between adjacent positions. This is because the code is fashioned so that there is only a single bit change between all adjacent positions. For example, if a binary code were used to encode position, changing from position-15 to position-16 would cause five bits in the code to change state. If the mobile assembly stopped between position-15 and position-16 there is a chance that all of the bits would not change state and that an erroneous position would be reported. In such a case, a Gray code would report either position-15 or position-16 and no other. The aforementioned third rail can also be used to return position data to a central sequencer and controller.

[0044] As the position of mobile assembly **302** changes, the angle between the subject and strobe light **308** also changes. It is desirable that strobe light **308** point directly at the subject, regardless of the position of mobile assembly **302**. To facilitate this, strobe light **308** is rotatably coupled to mobile assembly **302** through a motorized coupling **310**. Using a stepper motor similar to that of mobile assembly **302**, the angle of the strobe light can be varied according to the position of the mobile assembly along the length of the leg **306**. In this manner, strobe light **308** can remain aimed directly at the subject, regardless of its position along the leg.

[0045] FIG. **4A** depicts a typical strobe light firing sequence in accordance with one embodiment of the present invention. As previously described, the firing of a strobe light results in the formation of a single image for the multi-image polynomial texture mapping data set. The six depictions **402, 404, 406, 408, 410,** and **412** show a single support apparatus with six strobe lights, two of which are mounted to each leg. In each of the six depictions **402, 404, 406, 408, 410,** and **412** a single strobe light is shown firing. For example, in depiction **402**, the top strobe light on the left leg of the support apparatus is shown firing. In depiction **404**, the top strobe light on the center leg of the support apparatus is shown firing. In total, the sequence of strobe light firings results in the creation of six data images.

[0046] FIG. **4B** depicts a typical strobe light firing sequencer **414** in accordance with one embodiment of the present invention. The sequencer **414** is connected to a set of strobe lights **416** and a camera **418**. In this example, there are six strobe lights. The sequencer **414** can be programmed to fire the individual strobe lights in any order. After each strobe light is fired, the camera **418** is advanced in preparation for the next photograph.

[0047] FIG. **5** is a flowchart diagram of the operations for obtaining a set of digital photographs **500** with manually positioned strobe lights to be used with polynomial texture mapping, in accordance with one embodiment of the present invention. As previously described, polynomial texture mapping is a digital image processing technique that relies on having a number of images of the subject

object. For each of the images, the camera and subject remain in the same position and the position of the lighting changes.

[0048]   First, the support apparatus is placed with the camera substantially normal to the subject (502). If the camera has a zoom lens, then the focal length of the lens is adjusted to optimally frame the subject. The camera lens is then focused and the optimum lens aperture is determined and set.

[0049]   Next, the strobe lights are positioned at the first detent positions (504) along the length of the legs. Rather than having a separate strobe light at every lighting position, the support apparatus can be made lighter and more portable by having only one to several strobe lights per leg. Moving the strobe lights to different positions along the length of the leg allows a multiplicity of images to be obtained using as few as one strobe light per leg.

[0050]   The strobe sequencer is now set to select the first strobe light (506). The sequencer controls the camera and the sequential firing of the strobe lights. The sequencer can be either automatic or manual. Before the first exposure is made, the light-shielding screens can be attached to the support apparatus as needed to block ambient light from the photographs.

[0051]   With the support apparatus now in position, the camera focused, the strobe lights positioned, and the sequencer set, the first sequence of photographs can now be taken. A "sequence" refers to a set of photographs with the strobe lights at a given position. Typically, multiple sequences are used to collect a set of images used for a single polynomial texture mapping analysis.

[0052]   Firing the strobe light while exposing the photograph (508) captures an image. Typically, a single strobe-lit photograph comprises the following steps. Upon receiving a signal from the sequencer, the camera lens diaphragm closes to its predetermined opening and the camera shutter opens. The strobe light is then fired. A built-in exposure sensor in the camera determines the length of the strobe light flash. After the strobe light is extinguished, the shutter is closed and the captured image is stored in the camera's memory.

[0053]   The sequencer then determines if the photographic sequence is complete
(510). If the sequence is not complete, then the sequencer advances the camera
and the next strobe light in the sequence is selected (512). A new photograph is
then taken as before in (508). If the sequence is complete, then it is decided if an
additional photograph sequence is desired (514).

[0054]   If an additional photograph sequence is desired, then the strobe lights are
positioned at the next detent positions (516). The sequencer is then set to select
the first strobe light (506) and then the sequence of photographs is taken as
before. If an additional photograph sequence is not desired, then the process is
done (518).

[0055]   FIG. 6 is a flowchart diagram of the operations for obtaining a set of
digital photographs 600 with automatically positioned strobe lights to be used
with polynomial texture mapping, in accordance with one embodiment of the
present invention. As previously described, polynomial texture mapping is a
digital image processing technique that relies on having a number of images of the
subject object. For each of the images, the camera and subject remain in the same
position and the position of the lighting changes.

[0056]   First, the support apparatus is placed with the camera substantially
normal to the subject (602). If the camera has a zoom lens, then the focal length of
the lens is adjusted to optimally frame the subject. The camera lens is then
focused and the optimum lens aperture is determined and set.

[0057]   As with the support apparatus in FIG. 5 having manually positioned
strobe lights, the support apparatus can be made lighter and more portable by
having only one automatically positioned strobe light per leg rather than having a
separate strobe light at every lighting position. Automatically moving the single
strobe light to different positions along the length of the leg allows a multiplicity
of images to be rapidly obtained.

[0058]   Next, the sequencer receives a parameter specifying the number of
photograph sequences (604) to be made. Based upon the number of photograph
sequences needed, the first and final strobe light positions along with any required

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intermediate positions can be calculated **(606)**. In one embodiment, constant linear displacement of the strobe light along the leg translates into variable linear angular elevation change of the strobe light with respect to the subject. For constant angular change between sequences, an alternate embodiment calculates separate linear displacements. This calculation varies with the total number of sequences desired. After calculating the strobe light positions, the strobe lights are moved to their first positions **(608)**.

[0059] The strobe light sequencer is now set to select the first strobe light **(610)**. The sequencer controls the camera and the sequential firing of the strobe lights. The sequencer is automatic. The light-shielding screens can be attached as needed to the support apparatus to block ambient light from the photographs before the first exposure is made.

[0060] Firing the strobe light while the camera lens is open **(612)** captures an image. As previously described, typically, a single strobe-lit photograph comprises the following steps. Upon receiving a signal from the sequencer, the camera lens diaphragm closes to its predetermined opening and the camera shutter opens. The strobe light is then fired. A built-in exposure sensor in the camera determines the length of the strobe flash. After the strobe light is extinguished, the shutter is closed and the captured image is stored in the camera's memory.

[0061] The sequencer then determines if the photographic sequence is complete **(614)**. If the sequence is not complete, then the sequencer advances **(616)** the camera and the next strobe light in the sequence is selected. A new photograph is then taken as before in **(612)**. If the sequence is complete, then it is decided if the strobe lights are at their final positions **(618)**.

[0062] If the strobe lights are not at their final positions, then the strobe lights move to the next position **(620)**. The sequencer is then set to select the first strobe light **(610)** and then the sequence of photographs is taken as before. If the strobe lights are at their final positions, then the process is done **(622)**.

[0063] While specific embodiments have been described herein for the purposes of illustration, various modifications may be made without departing from the

spirit and scope of the invention. For example, figures and descriptions above reference using embodiments of the present invention with polynomial texture mapping image process operation, however alternate embodiments of the present invention can be readily adapted for use with other image processing operation including, for example, shape from shading and others. These image-processing operations also would benefit by the portability of the present invention and the flexibility of positioning the lights and camera. Further, figures and descriptions also reference using a tripod having three support legs however, alternate embodiments contemplate using greater or fewer legs and support for the apparatus or to provide additional azimuthal angles for mounting strobe lights. These additional legs can be used for support or purely for additional azimuthal positions. Accordingly, the invention is not limited to the above-described embodiments, but instead is defined by the appended claims in light of their full scope of equivalents.